LHC Accelerator Research Program
Beam Instrumentation and Diagnostics

DOE Lehman Review

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John Byrd

LARP Beam Instrumentation and Diagnostic Techniques

LARP will help the LHC in 3 key areas:

- *Bring LHC to full energy*

  Betatron tune, coupling, and chromaticity control during ramp

- *Bring LHC to design luminosity*

  Real-time luminosity monitor

- *LHC machine protection*

  Longitudinal density monitors

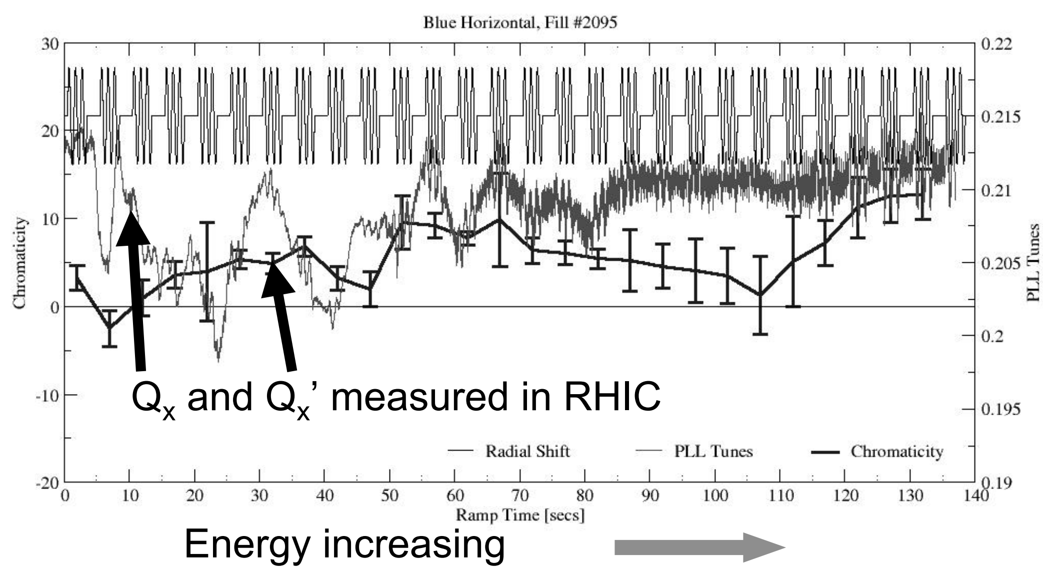
These contributions advance the state-of-the-art in beam instrumentation and have direct contributions to present and future US accelerator projects.

Also planning for R&D on additional instrumentation

Tune Control

- Challenge: persistent current effects in SC magnets can strongly perturb machine lattice, especially during energy ramp (aka “snapback”). Effects for LHC predicted to be large.
  – Betatron tunes ($Q_{x,y}$) and chromaticities ($Q'_{x,y}=EdQ_{x,y}/dE$) can vary significantly due to “snapback” resulting in beam loss, emittance growth.
- Solution: make fast, precision Q, Q’ measurements and use these signals to feedback to tuning quadrupoles and sextupoles.

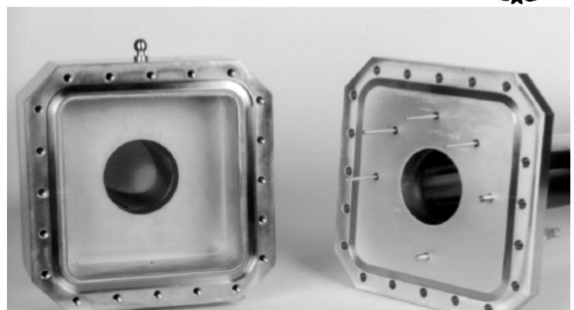
Effects of persistent currents in RHIC



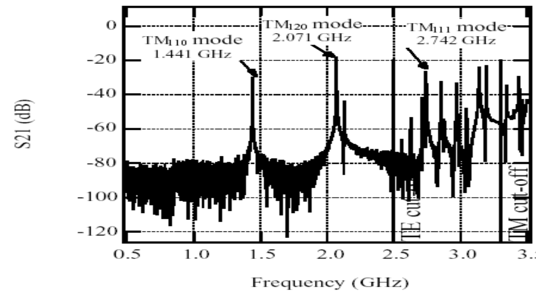
Tune and Chromaticity Measurement

Tunes
- EM Pickups
  – resonant cavity
  – high bandwidth Schottky array
- Optical position monitor
  – use edge radiation at low energy

Chromaticities
- Slightly vary energy and measure tunes
  – DC phase modulation
  – fast phase modulation
- Direct measurement along bunch length



RHIC Schottky cavities and response

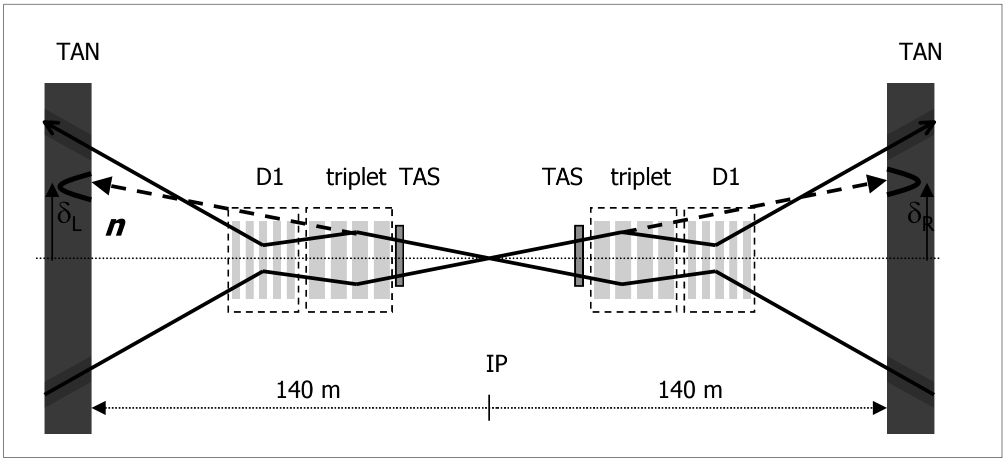


Tune Control Status

- Serious work just getting started…
- RHIC/CERN collaboration established
- Workshop held at Fermilab in May 03
- Discussions on choice of tune pickup in progress
- Coordinate LARP efforts with ongoing work at RHIC and Tevatron.

High Bandwidth Luminosity Monitor

Instrument US-built TAN absorbers to measure and optimize the luminosity of colliding bunch pairs with 40 MHz resolution



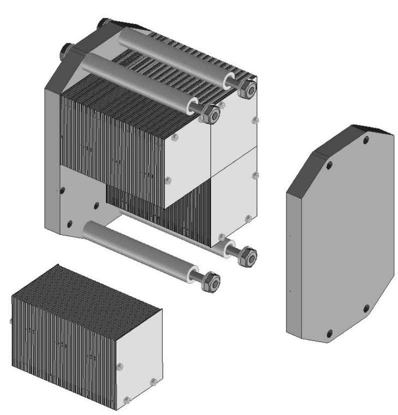
LHC Luminosity Measurement

The challenge:

- 1% absolute precision and <0.5% relative precision as a feedback signal for luminosity optimization
- Long term stability (~1 month) for calibration with detectors
- High radiation environment (100 MGy/year)
- Bunch-by-bunch capability (25 nsec separation)

The solution:

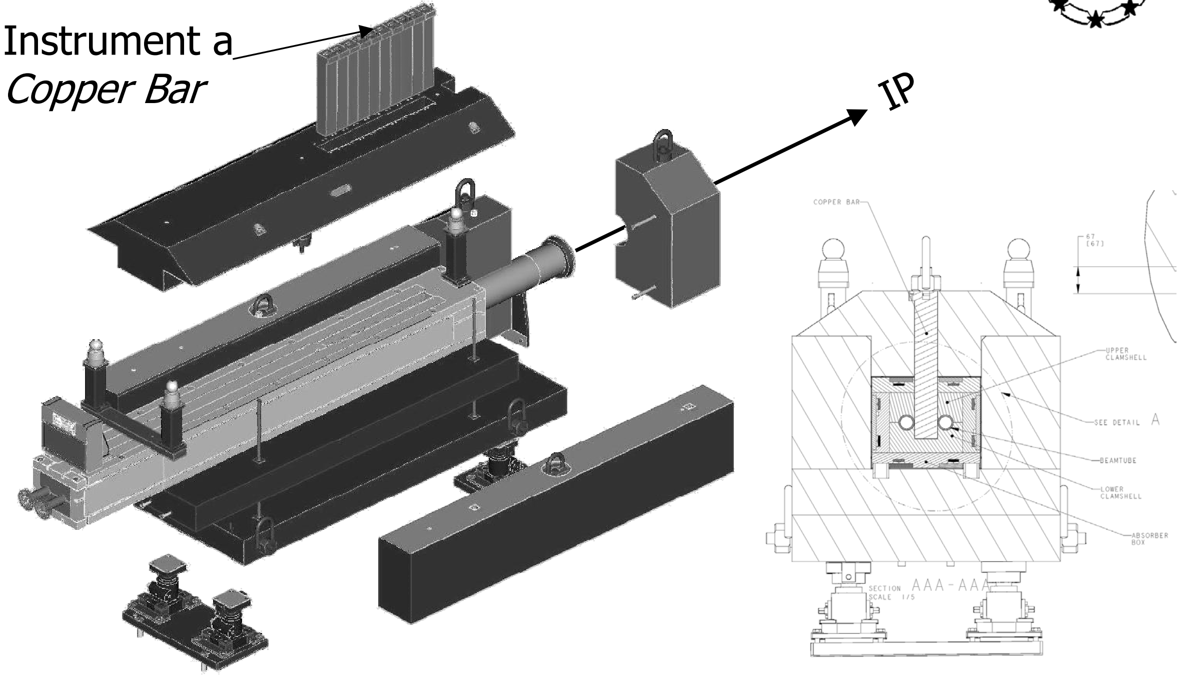
- Segmented, multi-gap, pressurized ArN_2 gas ionization chamber constructed of rad hard materials
- CERN group is developing CdTe technology in parallel.



Luminometer details

- Segmented, multi-gap, pressurized gas ionization chamber constructed of rad hard materials
- 3-11 atmospheres Ar + 2%N_2 gas mixture, e^- drift velocity 3.2 cm/μs
- Low noise bi-polar transistor pre-amplifier "cold" cable termination, $ENC_\delta \sim 1{,}824\ e^-$
- Pulse shaper, $\tau = 2.5$ ns
- 3 m radiation hard cable between ionization chamber and front end electronics, radiation dose to electronics < 100 Gy/oper yr
- S/N ~ 5 for single pp interaction

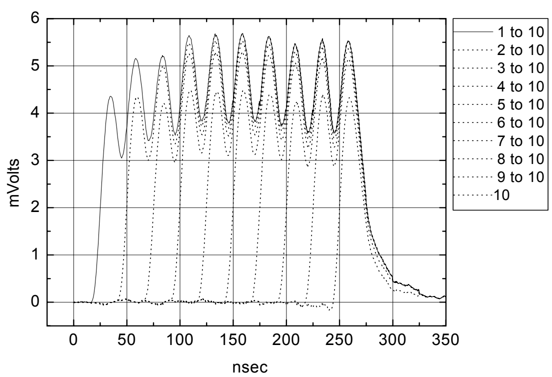
Instrumented TAN absorber



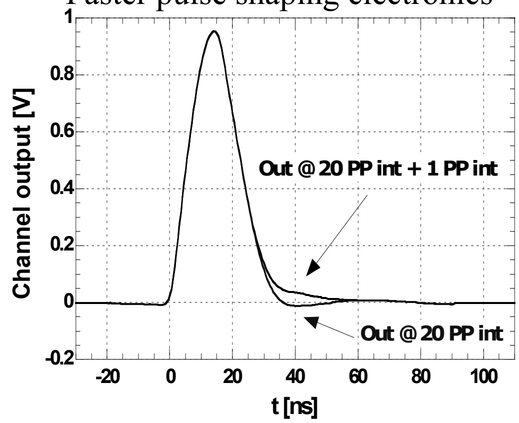
Bunch-to-bunch Luminosity Measurement

- Peaking time is less than the 25 ns bunch spacing
- Pulse train obtained by superposition of single pulses

Beam test at SPS- Sept. 01

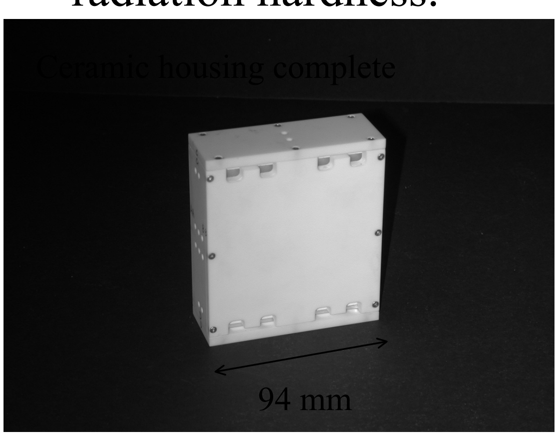


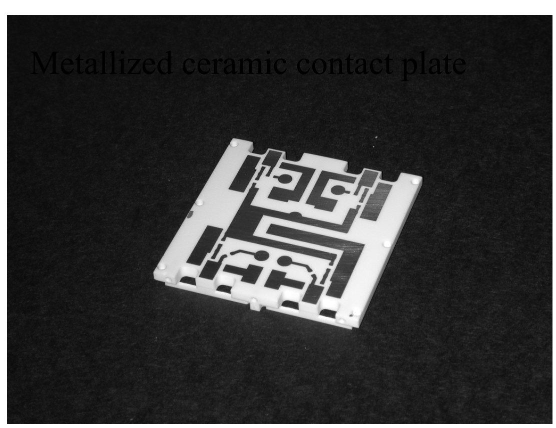
Faster pulse shaping electronics



LUMI Status

- Second prototype under construction
- Beam tests planned at ALS and Fermilab Booster (Ar-N_2 and CdTe). Tests of time response and radiation hardness.





LHC Longitudinal Charge Density

LHC beam carries 350 MJ. Beam loss in magnets can cause severe damage.

- Machine protection issues for study include:
  - Debunched beam at injection
  - Population in abort gap
  - Ghost bunches
  - Bunch core and tails
- Requirements:
  - 10^4 dynamic range
  - 20 samples/bunch giving $\pm 2\sigma$ (1120 psec). Corresponds to 50 psec sampling resolution.
  - Do this for all buckets (h=35640!). Drives overall sampling rate.

The LDM will also be an invaluable tool for beam dynamics studies in LHC.

LHC Longitudinal Charge Density Specs

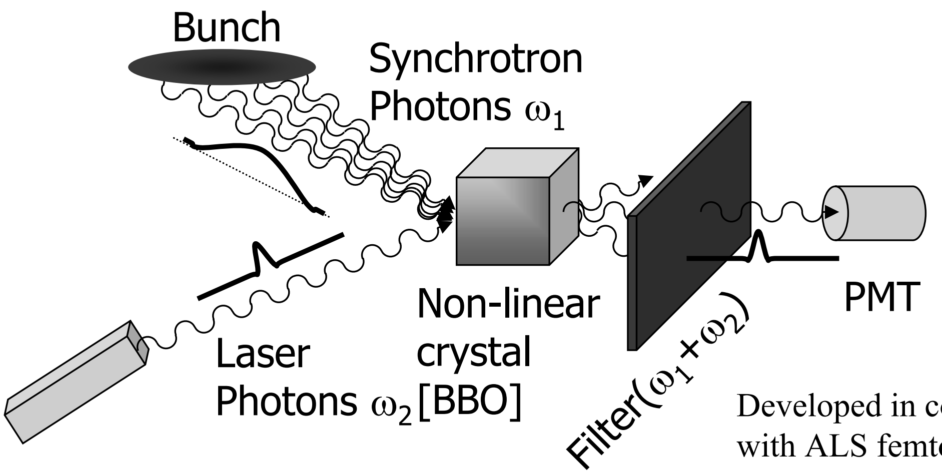
Function	**Beam energy TeV**	**Nominal peak density*, p/ps**	**Resolution, p/ps**	**Integration time**
Debunched beam	0.45	1.0×10^8	2×10^4	~10 sec
Abort gap population	7.0	2.0×10^8	60	~ 100 ms
Ghost bunches	7.0	2.0×10^8	2×10^4	~ 10 sec
Tails	7.0	2.0×10^8	$2 \pm 1 \times 10^4$	~ 10 sec
Bunch core	7.0	2.0×10^8	$2 \pm 1 \times 10^6$	~ 1 msec

* $N_b = 10^{11}$

Requirements (from. C. Fischer, LHC-B-ES-0005.00 rev 2.0, 07 Jan 03)

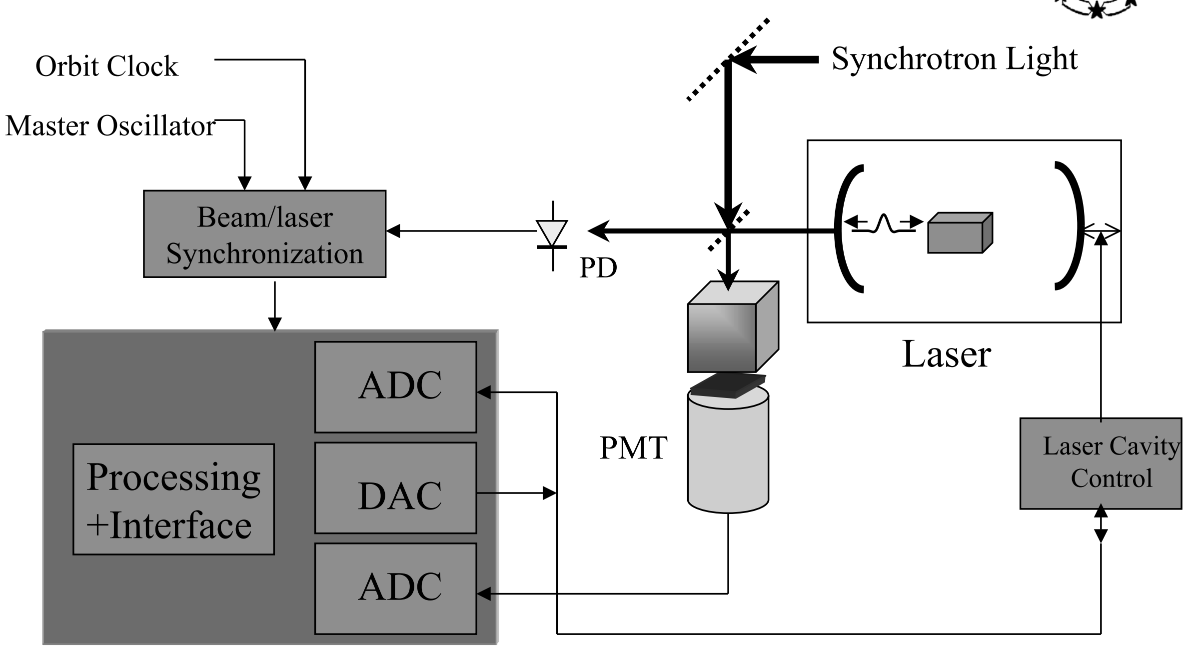
Solution: Optical Sampling Technology

- Use nonlinear mixing of synchrotron radiation with a 50 psec laser pulse to sample the longitudinal bunch profile



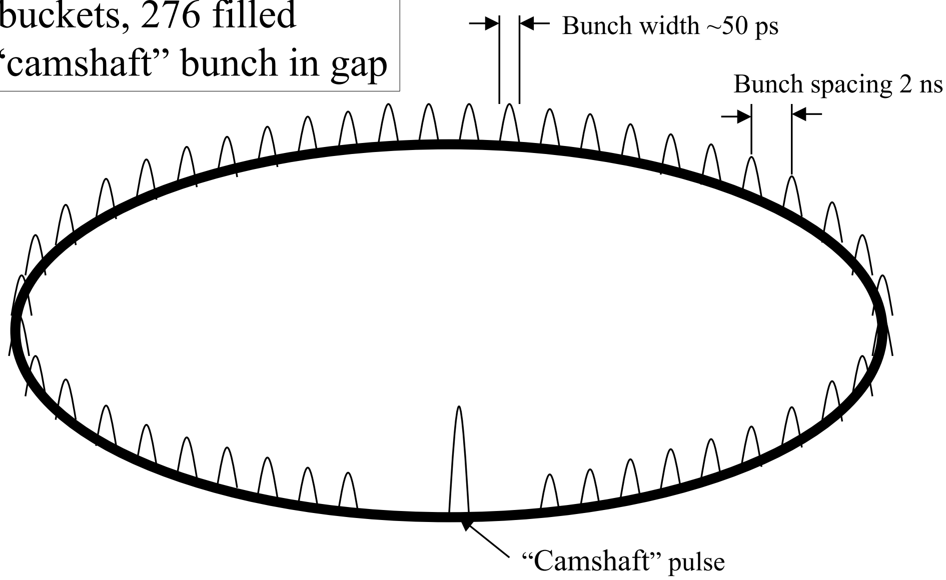
Developed in collaboration with ALS femtoslicing program.

Longitudinal Density Monitor

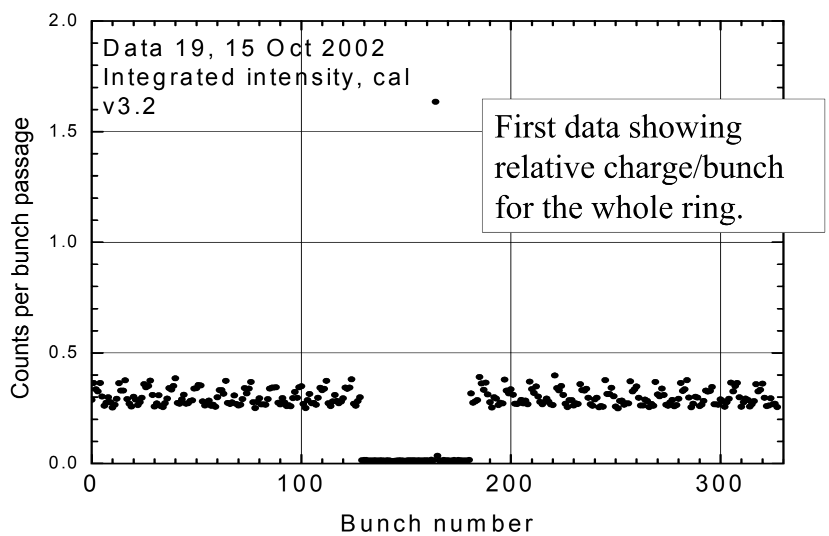


Test the concept at the ALS

ALS bunch structure
328 buckets, 276 filled
big “camshaft” bunch in gap

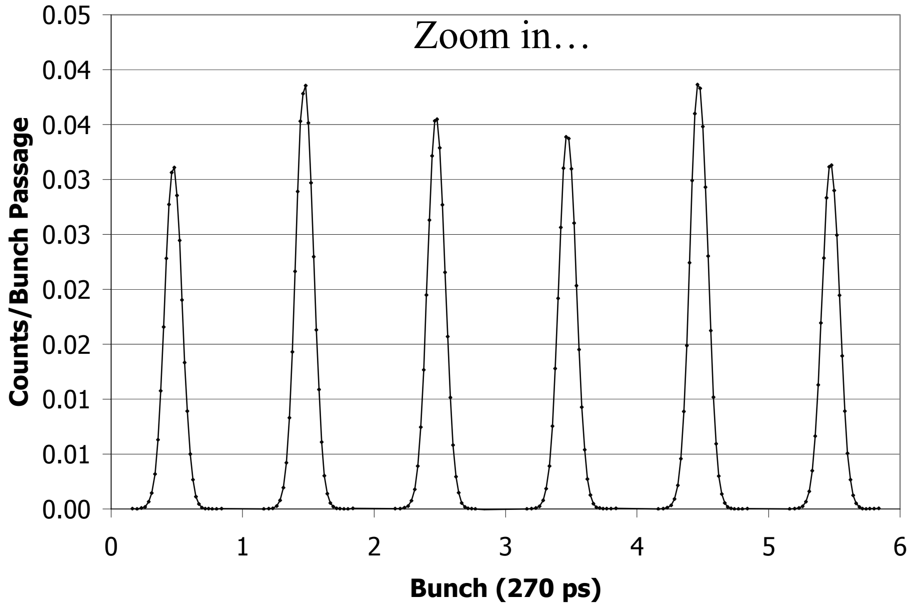


ALS LDM Tests



First data showing relative charge/bunch for the whole ring.

ALS LDM tests (cont.)



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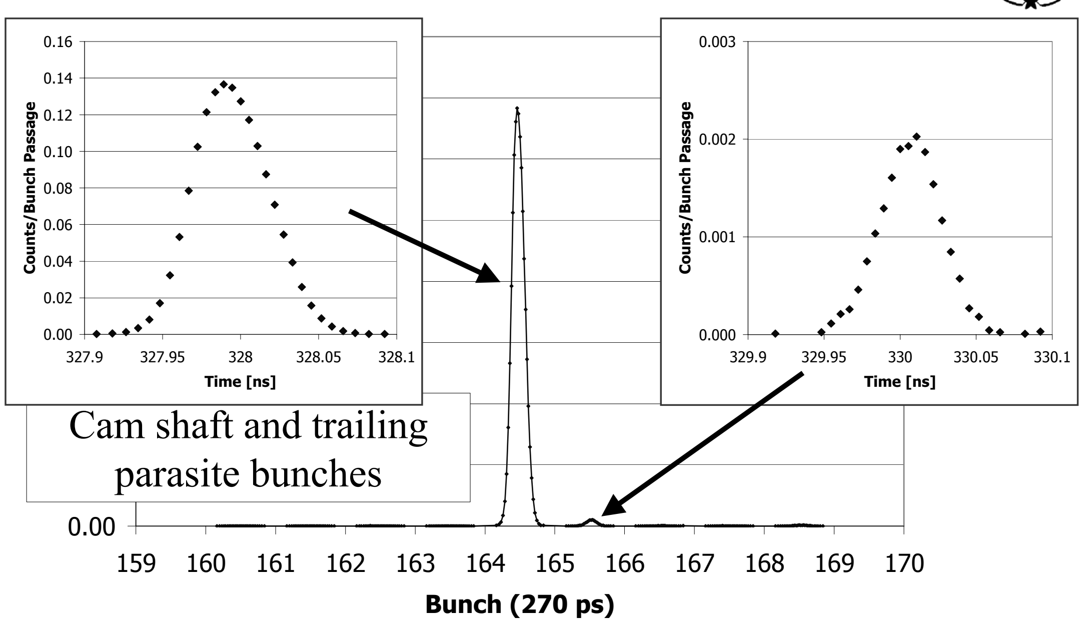
ALS LDM tests (cont.)



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LDM Status

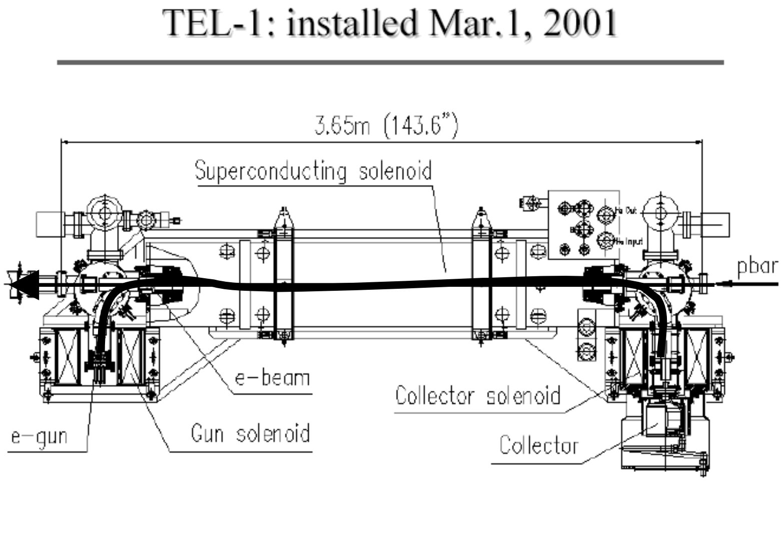
- Continuing studies on ALS.
- Considering applications at other facilities.
- Integrate experimental setup as an “instrument”
  – Identify appropriate laser for LHC
  – Combine all optics into laser housing
- Coordinate with CERN for use with synchrotron sources
- Coordinate instrument interface with LHC commissioning and operations

Additional instrumentation/techniques

- Beam/Beam studies
  – AC dipole for reactive excitation of beam
  – beam-beam compensation with electron lens or wire
- Electron Cloud
  – In situ low energy electron spectrometer

These will be added to the LARP program as need and funding permit.

Electron Lens

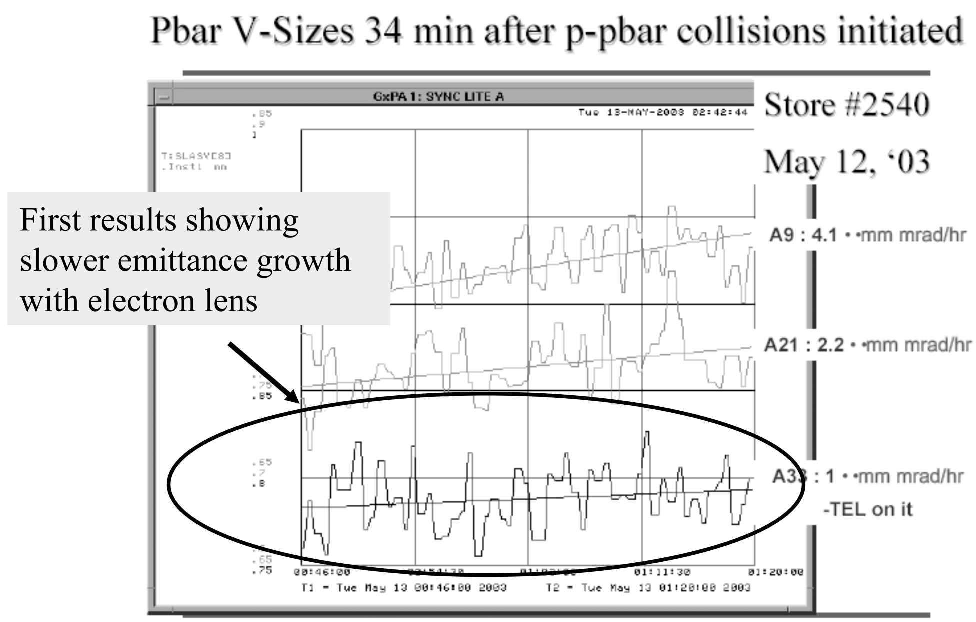


Concept: low energy electron beam with tailored profile to compensate beam-beam kick from proton beam.

Tevatron Electron Lens (TEL) has been installed and studied for the past two years.

Tevatron Electron Lens

Pbar V-Sizes 34 min after p-pbar collisions initiated



Summary

We will build, commission, and integrate into LHC operations advanced instrumentation and diagnostics for helping LHC

- reach design energy
- reach design luminosity

This program will advance the US HEP program by

- enhancing US accelerator skills
- developing advanced diagnostic techniques that will apply to present and future US programs
- maximize LHC performance